

VARIOUS PRECONCENTRATOR STRUCTURES FOR DETERMINATION OF ACETONE IN A WIDE RANGE OF CONCENTRATION

Artur RYDOSZ¹, Dagmara MICHON¹, Krzysztof DOMANSKI²,
Wojciech MAZIARZ¹, Tadeusz PISARKIEWICZ¹

¹Department of Electronics, Faculty of Computer Science, Electronics and Telecommunications,
AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Krakow, Poland

²Institute of Electron Technology, Pulawska 34, 05-500 Piaseczno, Poland

artur.rydosz@agh.edu.pl, dagmara.kwapinska@student.agh.edu.pl, kdoman@ite.waw.pl,
wojciech.maziarz@agh.edu.pl, tadeusz.pisarkiewicz@agh.edu.pl

DOI: 10.15598/aeec.v14i1.1525

Abstract. *In this paper, the investigation results on preconcentration of acetone at various initial concentrations are presented. The structures were made of conventional materials, such as stainless steel, quartz tube as well as fabricated in MEMS technology – micro-preconcentrators. All structures have the same ‘active’ area to obtain more suitable comparison. The adsorbent materials were selected from commercial available Sigma-Aldrich Carbon Adsorbent Sampler Kit, consisting of 8 various adsorbents. The highest concentration factors were obtained by utilization of micropreconcentrator filled with Carboxen-1018, which is recommended for adsorption of C₂-C₃ compounds. The preconcentrators were placed into microsystem, and semiconductor gas sensor array was used as a detector unit. The microsystem was previously tested and designed for exhaled breath acetone analysis. The obtained results show that micropreconcentrator can be a useful tool for an increasing sensor sensitivity.*

Keywords

Acetone, MEMS technology, micropreconcentrators, preconcentration.

1. Introduction

Acetone is widely used in many industrial processes, it can be found in many goods used in everyday life as well, such as e.g. lacquer, varnish, rubber, plastics, etc. The occupational exposure limit for ace-

tone in the EU, USA, Japan, as a time-weight average concentration over an 8-hour work shift, equals 2400 mg · m⁻³ (1000 ppm), respectively [1]. Based on guidelines provided by the National Institute for Occupational Safety and Health (NIOSH), concentrations of approximately 250-500 ppm were reported to cause slight irritations of noses, throats, lungs and eyes. After exposure to the concentration of 1000 ppm symptoms such as headache, headedness, dizziness, unsteadiness and confusion are common. Inhalation of concentrations higher than 2000 ppm can cause a feeling of drunkenness, drowsiness, nausea and vomiting. Higher concentrations can result into collapse, coma and death. Furthermore, acetone can be also determined in the exhaled breath with emphasis on type-1 diabetes mellitus subjects [2], [3], [4] and [5]. The exhaled acetone is usually in the range of 0.2 – 1.8 ppm for healthy people, and in the range of 1.25 – 2.4 ppm for people with diabetes [6]. Therefore, acetone is an attractive compound that have to be measured in a wide range of concentrations. The concentration range from 50 - 5000 ppm is covered by commercially available gas sensors, i.e. TGS 822, TGS 823 (Figaro Inc, USA), AF63 (Scimarec Ceramic Technology, UAZ). However, the gas sensors for acetone in the concentrations below 50 ppm are still under investigation [7], [8], [9] and [10]. Currently available instruments are based on laboratory systems such as: gas chromatography-mass spectrometry (GC/MS) [11], proton transfer reaction mass spectrometry (PTR-MS) [12], selected ion flow tube mass spectrometry (SIFT-MS) [13], etc. However, the size, cost and complexity associated with these instruments preclude their routine application. One of the cheap and very effective method to increase the

limit of detection (LOD) to measure low amounts of gasses is the application of gas preconcentrator structures [14], [15] and [16].

Conventional preconcentrators are usually made of glass or stainless steel tubes filled with an adsorbent material [17], [18]. These structures have lateral dimensions and power consumption, which is too high to be applied in portable applications. A solution that overcomes these limitations are micropreconcentrators made in various technologies [19], [20]. In this study, the preconcentrators made in various techniques for determination of acetone in a wide range of concentrations are presented and discussed. The main goal is to have a fast extraction while maintaining high sensitivity. Voiculescu et al. [21] have reported the comparison of the analyte concentration and time constant in micromachined and conventional preconcentrators. The authors reported that microfabricated preconcentrator devices are characterized by reduced dead volume and thermal mass and delivering a concentrated sample that has a narrow time-width pulse for analysis [21].

In this paper, the preconcentrators have the same volume of adsorbent material. The additive dimensions were as small as possible. In such solution, we compared the detector response for both conventional preconcentrators and micropreconcentrators (Fig. 1). As presented in the Fig. 1, the detector response is 5-times longer for conventional preconcentrators than for micropreconcentrators in both available technologies, i.e. MEMS (micro-electro-mechanical systems) [22], LTCC (low temperature cofired ceramics) [23].

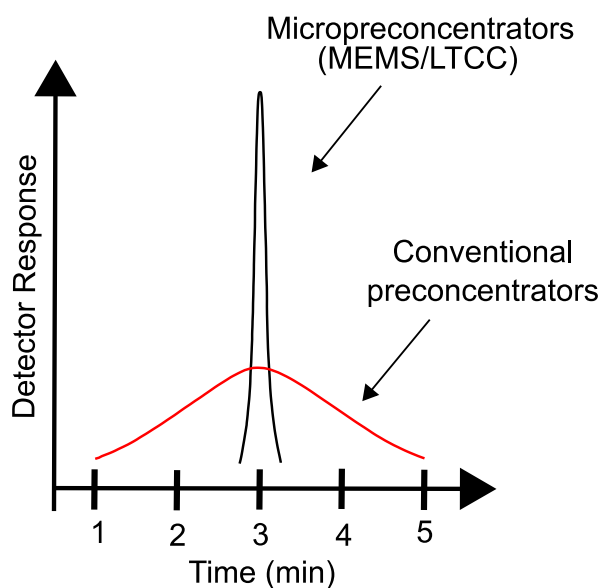


Fig. 1: Comparison of the detector response and time constant in micropreconcentrators and conventional preconcentrators.

2. Experimental Results

The preconcentration efficiency is measured using a concentration factor (CF) defined as the ratio of a gas concentration after and before the concentration process:

$$CF = \frac{V_{sample}}{V_{desorbed}} = \frac{V_{sample}}{W_h \cdot u}, \quad (1)$$

where V_{sample} is a sampled volume (liter), $V_{desorbed}$ is a desorbed volume (liter), W_h is a width of injection band (min), u is a desorption flow rate ($l \cdot \text{min}^{-1}$). Concentration factor theory is briefly described in the literature [24], [25] as well as various materials used in preconcentrators, i.e. polymer-coated microcolumns [26], Tenax polymer [14], [27]. The proposed preconcentrators were filled with different CMS (Carbon Molecular Sieve) adsorbent materials. The authors used a commercial available Carbon Adsorbent Sampler Kit (Sigma-Aldrich, St. Louis, MO 63178, USA) which contains 8 different adsorbent materials. This convenient kit allows a cost-effective way to evaluate several of special carbon adsorbents, i.e. Carboxen 569, Carboxen 1000, Carboxen 1012, Carboxen 1018, Carboxen 1021, Carbosieve G, Carbosieve S-III, Graphsphere 2016. As the authors focus on acetone analysis, after the pre-selecting, few promising adsorbent materials were selected: Carboxen-1018, Carboxen-1012, Carboxen-1003, Carboxen-1000 and Carboxen-569. They all are hydrophobic, have large surface area and grain diameters suitable to channel dimensions.

2.1. Conventional Preconcentrator – Quartz Tube

The preconcentrators were constructed from quartz-glass capillaries (0.2 mm i.d., 0.4 mm o.d.) cut to a length of 46.8 mm. The volume of the channel into preconcentrator is approximately 14.7 mm^3 . The mass of adsorbent packed into the tube ranged from 0.95 to 11.3 mg. A quartz wool was folded and inserted into each end of the preconcentrator to retain the adsorbent. Figure 2 shows the schematic view of the preconcentrator made of quartz-glass capillaries. The preconcentrator is based on a thermal desorption, therefore, a 650 mm Kanthal (Ni-Cr) wire was coiled around the tube.

2.2. Conventional Preconcentrator – Stainless-Steel Tube

The preconcentrator stainless steel internal and outer diameter are 0.7 mm and 1.2 mm, respectively. Therefore, the tube was cut to a length of 38.2 mm to provide approximately the same volume (14.7 mm^3) as in the

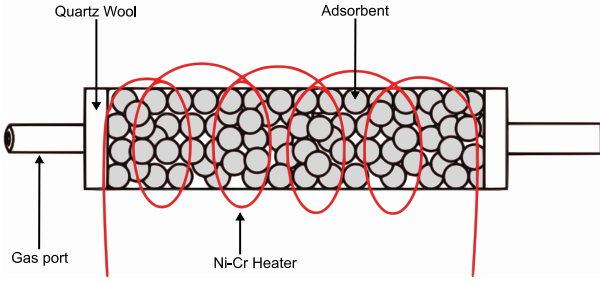


Fig. 2: Schematic view of the preconcentrator made of the quartz-glass capillary.

quartz-glass preconcentrators. As previously, the active carbon was held in place with quartz wool. The preconcentrator was heated using a coil of insulated nichrome wire.

2.3. Micropreconcentrator in Silicon Technology

The micropreconcentrators fabrication process was reported in detail in [28]. In this paper, we present investigation results obtained with the utilization of micropreconcentrator with microchannel dimensions: 0.35 mm x 0.35 mm x 120 mm. In this case, the microchannel volume is approximately 14.7 mm³. The approximate adsorbent weight in the microchannel equals 4 mg. The adsorbent material filled the microchannel from 80 % to 95 % and strongly depended on adsorbent material type. Figure 3 shows the SEM images of a Carboxen-1021 adsorbent material with marked grain dimensions (Fig. 3(a), Fig. 3(b)), sieve used for selection of molecules with specified grain size (Fig. 3(c)) and the channel filled with the Carboxen-1021 (Fig. 3(d)). To provide uniform temperature distribution inside the microchannel, the platinum microheater was deposited to cover the entire working area of the microchannel. The nominal resistance was 40 Ω ± 1 Ω. However, to achieve the selected desorption temperature the voltage supply of 13.4 V ± 0.3 V is required. Due to, portable electronic devices supply standards, the voltage supply should be decreased to 5 V or even 3.3 V. The micropreconcentrators with reduced capacity as well as with special designed thermal insulation, which can improve power consumption are under investigation.

2.4. Thermal and Electrical Measurements

As already mentioned, the preconcentrators are based on thermal desorption. While selected carbon adsorbents are stable to above 400 °C, the desorption temperature was set to 220 °C. A PID controller (Eu-

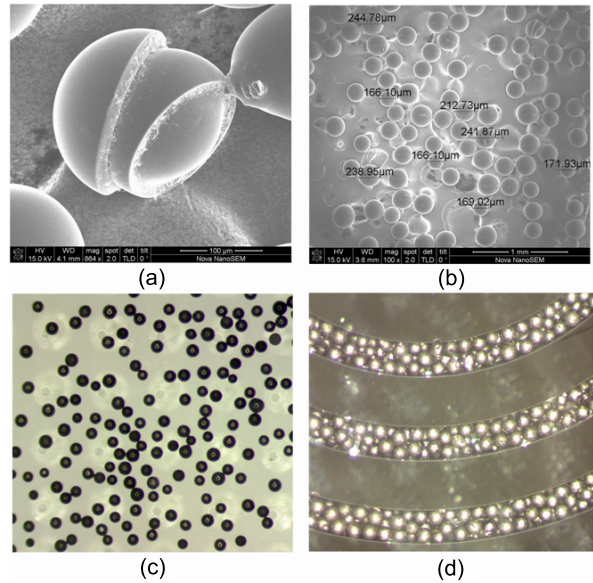


Fig. 3: The adsorbent Carboxen-1021: (a) SEM image of a single grain, (b) SEM image with molecule diameters, (c) sieve with adsorbent molecules, (d) the channel filled with the adsorbing material.

rotherm 2408, UK) and power supply (Motech PPS-1203, Taiwan) were used to control the heating profile for thermal desorption as well as during the adsorbent material activation. Figure 4 shows the relations between temperature and power consumption for three different designs: quartz-tube (Section 2.1.), stainless steel-tube (Section 2.2.) and MEMS (Section 2.3.). As presented in Fig. 4, the power consumption in MEMS micropreconcentrator is 4-times and 2-times lower than for stainless steel-tube and quartz-tube preconcentrators, respectively. It has to be underlined, that microchannel volume is the same for all compared designs.

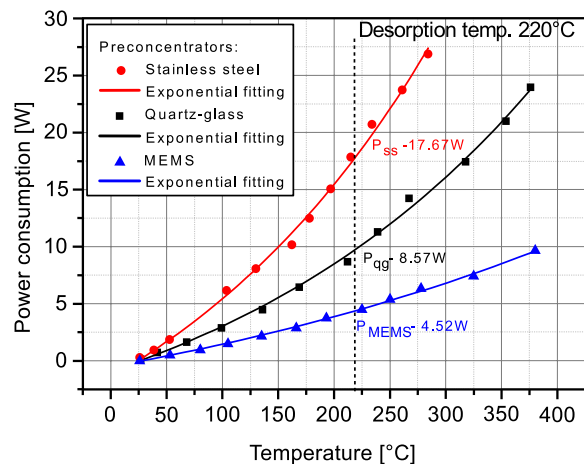


Fig. 4: Power consumption vs. temperature for preconcentrators made in different technologies.

2.5. Measurement Setup

Figure 5 shows a schematic view of the measurement system. As the sample gas, acetone with a concentration of 80 ppm, 8 ppm and 0.8 ppm was used. As the carrier gas, nitrogen (99.999 %) was used. The mass flow controller MFC (MKS Instruments, USA) provides a flow rate of 50 sccm. To obtain the best separation behaviour, temperature and flow rate are important parameters. Based on previously reported results [23], the desorption temperature was set to 220 °C and flow rate to 50 sccm. The first step is a purging phase of the system. In this step, the system is switched to desorption and the nitrogen flows through the system to clean (purge) all gas connection for at least 15 minutes at the room temperature. Before using the preconcentrators the adsorbent material has to be activated. The authors used typical time–temperature profiles for adsorbent activation: 0.5 h – 100 °C, 1 h – 200 °C, 1 h – 300 °C, 0.5 h – 350 °C and nitrogen as a carrier gas. After activation, the adsorption can be performed. The adsorption is performed at the room temperature and the gas flows past the preconcentration in adsorption direction (see Fig. 5). The breakthrough of acetone and thereafter the maximum possible acetone concentration can be calculated from Wheeler-Jonas formula:

$$t_b = \frac{W_e W_b}{C_0 Q} - \frac{\rho_B W_e}{k_v C_0} \ln \left(\frac{C_0 - C_X}{C_X} \right), \quad (2)$$

where t_b is breakthrough time (min), W_e is the equilibrium adsorption capacity ($\text{g} \cdot \text{g}^{-1}$), W_B is the bed mass (g), C_0 is the challenged concentration ($\text{g} \cdot \text{l}^{-1}$), C_X is the fraction of C_0 where breakthrough is measured ($\text{g} \cdot \text{l}^{-1}$), k_v is the kinetic rate coefficient (min^{-1}), ρ_B is density ($\text{g} \cdot \text{cm}^{-3}$), the Q is gas flow rate ($\text{l} \cdot \text{min}^{-1}$). In the case of study, t_b was reached after approximately 60 min.

In the case study, after the adsorption process, the valves are activated (by applying voltage) and the system is switched to desorption process (see Fig. 5). The preconcentrator temperature was ramped at controllable rates under homemade software control by monitoring the temperature and adjusting the voltage to the resistive heater. The microconcentrators have deposited a platinum heater, which was also used as a rapid temperature detector. To control the temperature in conventional preconcentration designs the thermocouple type-K was used. The nitrogen flows through the preconcentrator and acetone is desorbed from the adsorbent material. Thereby, it causes output signal on the gas sensors. The gas sensors responses are measured by electrometer and transferred to the PC.

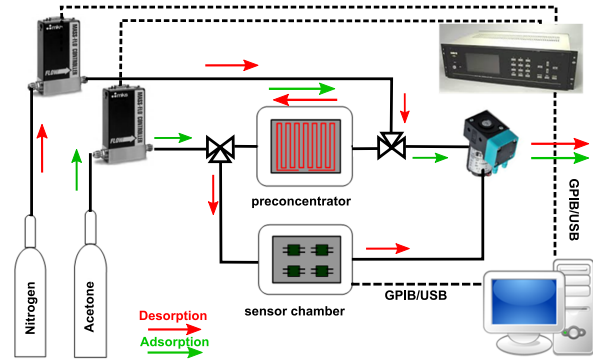


Fig. 5: Schematic view of the measurement setup. Red and green arrows show gas flow through the microsystem at desorption and adsorption, respectively.

3. Results and Discussion

The acetone concentration factor (CF) was evaluated for the preconcentrators, using different initial acetone concentrations (0.8, 8, 80 ppm) and different adsorption times (from 5 to 60 min).

Figure 6 shows CFs obtained for microconcentrator filled with various adsorbent materials at constant adsorption time (60 min), and various acetone concentration, i.e. 0.8 ppm, 8 ppm, 80 ppm. The CFs obtained for 0.8 ppm were multiplied 25 times for better comparison. The results have proved that Carboxen-1018 is the best adsorbent material for acetone preconcentration from Carbon Adsorbent Sampler Kit. However, Carboxen-1003, Carboxen-1000 and Carboxen-1021 can be also worth considering, mainly due to the fact that the Carboxen-1018 is hardly available.

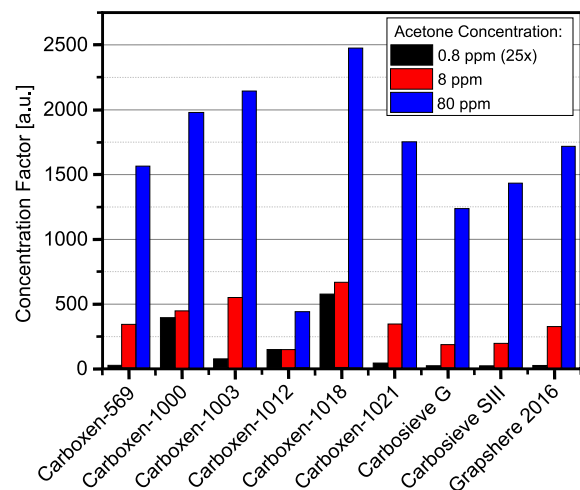


Fig. 6: Concentration Factors for different adsorbent materials from Carbon Adsorbent Sampler Kit at various initial acetone concentrations obtained by utilization of microconcentrator (adsorption time: 60 min, flow rate: 50 ml/min). CF obtained for acetone at 0.8ppm were multiplied 25 times.

Figure 7 shows the concentration factors for Carboxen-1018 for various preconcentration realization in the function of adsorption time. As it can be noticed, the CFs measured by utilization of micropreconcentrators are at least 3- and 4-times higher than for quartz-tube and stainless-steel tube preconcentrators, respectively.

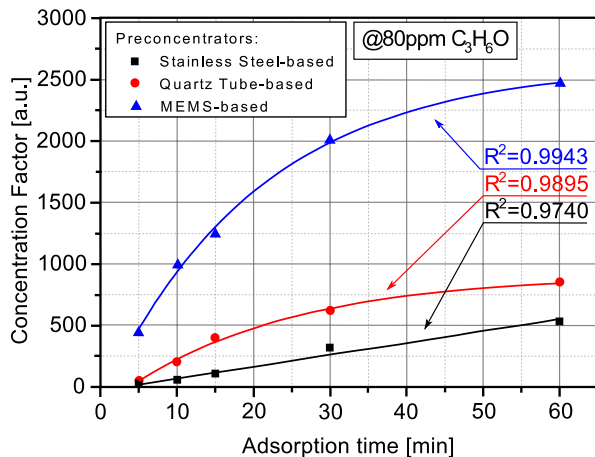


Fig. 7: Concentration Factor (with regression lines) for various preconcentrator designs in function of adsorption time for 80 ppm of acetone.

4. Conclusion

In order to overcome the limits in the sensitivity, the various preconcentrator structures were used, i.e. quartz-tube-based, stainless steel-based, micropreconcentrator. The adsorbent material has been chosen from a commercial available Carbon Adsorbent Sampler Kit. The adsorption-desorption cycles have been programmed applying power supply pulses to the heater and stabilized by PID controller. The results demonstrated that the Carboxen-1018 is suitable adsorbent material for acetone concentrations. The results prove that CFs obtained in micropreconcentrators are higher than in conventional ones. Moreover, micropreconcentrator require less power to achieve dedicated desorption temperature. Therefore, the micropreconcentrator can certainly be applied to the microsystems for low gas detection applications.

Acknowledgment

The work was financial supported by the National Science Centre, DEC-2013/09/N/ST7/01232.

References

- [1] National Institute of Occupational Safety and Health. *Occupational Safety and Health Guideline for Acetone*. Atlanta. 1988. Available at: <http://www.cdc.gov/niosh/docs/81-123/pdfs/0004.pdf>.
- [2] TASSOPOULOS, C., D. BARNETT and T. RUSSEL FRASER. Breath-acetone and blood-sugar measurements in diabetes *The Lancet*. 1969, vol. 293, iss. 7609, pp. 1282–1286. ISSN 0140-6736. DOI: 10.1016/S0140-6736(69)92222-3.
- [3] GUO, D., D. ZHANG, L. ZHANG and G. LU. Non-invasive blood glucose monitoring for diabetes by means of breath signal analysis. *Sensors and Actuators B: Chemical*. 2012, vol. 173, iss. 1, pp. 106–113. ISSN 0925-4005. DOI: 10.1016/j.snb.2012.06.025.
- [4] MIEKISCH, W., J. K. SCHUBERT and G. F. E. NOELDE-SCHOMBURG. Diagnosis potential of breath analysis - Focus on volatile organic compounds. *Clinica Chimica Acta*. 2004, vol. 347, iss. 1–2, pp. 25–39. ISSN 0009-8981. DOI: 10.1016/j.cccn.2004.04.023.
- [5] FLEISCHER, M., E. SIMON, E. RUMPEL, H. ULMER, M. HARBECK, M. WANDEL, C. FIETZEK, U. WEIMAR and H. MEIXNER. Detection of volatile compounds correlated to human diseases through breath analysis with chemical sensors. *Sensors and Actuators B: Chemical*. 2002, vol. 83, iss. 1–3, pp. 245–249. ISSN 0925-4005. DOI: 10.1016/S0925-4005(01)01056-5.
- [6] ZHANG, Q., P. WANG, J. LI and X. GAO. Diagnosis of diabetes by image detection of breath using gas-sensitive lps. *Biosensors and Bioelectronics*. 2000, vol. 15, iss. 5–6, pp. 249–256. ISSN 0956-5663. DOI: 10.1016/S0956-5663(00)00064-6.
- [7] LIU, S., F. ZHANG, H. LI, T. CHEN and Y. WANG. Acetone detection properties of single crystalline tungsten oxide plates synthesized by hydrothermal method using cetyltrimethyl ammonium bromide supermolecular template. *Sensors and Actuators B: Chemical*. 2012, vol. 162, iss. 1, pp. 259–268. ISSN 0925-4005. DOI: 10.1016/j.snb.2011.12.076.
- [8] KIM, S., S. PARK, S. PARK and C. LEE. Acetone sensing of Au and Pd-decorated WO₃ nanorod sensors. *Sensors and Actuators B: Chemical*. 2015, vol. 209, iss. 1, pp. 180–185. ISSN 0925-4005. DOI: 10.1016/j.snb.2014.11.106.
- [9] XIAO, T., X. Y. WENG, Z. H. ZHAO, L. LI, L. ZHANG, H. C. YAO, J. S. WANG and Z.

- J. LI. Highly sensitive and selective acetone sensors based on C-doped WO_3 for potential diagnosis of diabetes mellitus. *Sensors and Actuators B: Chemical*. 2014, vol. 199, iss. 1, pp. 210–219. ISSN 0925-4005. DOI: 10.1016/j.snb.2014.04.015.
- [10] RIGHETTONI, M., A. TRICOLI, S. GASS, A. SCHMID, A. AMANN and S. E. PRATSI-NIS. Breath acetone monitoring by portable Si: WO_3 gas sensors. *Analytica Chimica Acta*. 2012, vol. 738, iss. 1, pp. 69–75. ISSN 0003-2670. DOI: 10.1016/j.aca.2012.06.002.
- [11] KOYANAGI, G. K., V. KAPISHON, V. BLAGOJEVIC and D. K. BOHME. Monitoring hydrogen sulfide in simulated breath of anesthetized subjects. *International Journal of Mass Spectrometry*. 2013, vol. 354–355, iss. 1, pp. 139–143. ISSN 1387-3806. DOI: 10.1016/j.ijms.2013.05.024.
- [12] MOSER, B., F. BODROGI, G. EIBL, M. LECHNER, J. RIEDER and P. LIRK. Mass spectrometric profile of exhaled breath-field study by PTR-MS. *Respiratory Physiology & Neurobiology*. 2005, vol. 145, iss. 2–3, pp. 295–300. ISSN 1569-9048. DOI: 10.1016/j.resp.2004.02.002.
- [13] DISKIN, A. M., P. SPANEL and D. SMITH. Time variation of ammonia, acetone, isoprene and ethanol in breath: A quantitative SIFT-MS study over 30 days. *Physiological Measurement*. 2003, vol. 24, iss. 1, pp. 107–120. ISSN 0967-3334. DOI: 10.1088/0967-3334/24/1/308.
- [14] CAMARA, E. H. M., P. BREUIL, D. BRIAND, N. F. DE ROOIJ and C. PIJOLAT. A micro gas preconcentrator with improved performance for pollution monitoring and explosives detection. *Analytica Chimica Acta*. 2012, vol. 688, iss. 2, pp. 175–182. ISSN 0003-2670. DOI: 10.1016/j.aca.2010.12.039.
- [15] DOW, A. B. A. and W. LANG. A micromachined preconcentrator for ethylene monitoring system. *Sensors and Actuators B: Chemical*. 2010, vol. 151, iss. 1, pp. 304–307. ISSN 0925-4005. DOI: 10.1016/j.snb.2010.09.029.
- [16] LAHLOU, H., X. VILANOVA and X. CORREIG. Gas phase micro-preconcentrators for benzene monitoring: A review. *Sensors and Actuators B: Chemical*. 2013, vol. 176, iss. 1, pp. 198–210. ISSN 0925-4005. DOI: 10.1016/j.snb.2012.10.004.
- [17] CAI, Q. Y., J. PARK, D. HELDSINGER, M. D. HSIEH and E. T. ZELLERS. Vapor recognition with an integrated array of polymer-coated flexural plate wave sensors. *Sensors and Actuators B: Chemical*. 2000, vol. 62, iss. 2, pp. 121–130. ISSN 0925-4005. DOI: 10.1016/S0925-4005(99)00381-0.
- [18] NAKAMOTO, T., Y. ISAKA, T. ISHIGE and T. MORIIZUMI. Odor-sensing system using preconcentrator with variable temperatures. *Sensors and Actuators B: Chemical*. 2000, vol. 69, iss. 1–2, pp. 58–62. ISSN 0925-4005. DOI: 10.1016/S0925-4005(00)00388-9.
- [19] LI, M., S. BISWAS, M. H. NANTZ, R. M. HIGASHI and X. A. FU. A microfabricated preconcentration device for breath analysis. *Sensors and Actuators B: Chemical*. 2013, vol. 180, iss. 1, pp. 130–136. ISSN 0925-4005. DOI: 10.1016/j.snb.2012.07.034.
- [20] TIAN, W. C., T. H. WU, C. J. LU, W. R. CHEN and H. J. SHEEN. A novel micropreconcentrator employing a laminar flow patterned heater for micro gas chromatography. *Journal of Micromechanics and Microengineering*. 2012, vol. 22, iss. 6, pp. 065014–065022. ISSN 0960-1317. DOI: 10.1088/0960-1317/22/6/065014.
- [21] VOICULESCU, I., M. ZAGHLOUL and N. NARASHIMHAN. Microfabricated chemical preconcentrators for gas-phase microanalytical detection systems. *Trends in Analytical Chemistry*. 2008, vol. 27, iss. 4, pp. 327–343. ISSN 0165-9936. DOI: 10.1016/j.trac.2008.01.016.
- [22] RYDOSZ, A. Micropreconcentrators in Silicon-Glass Technology for the Detection of Diabetes Biomarkers. *Journal of Microelectronics, Electronic Components and Materials*. 2014, vol. 44, iss. 2, pp. 126–136. ISSN 2232-6979.
- [23] RYDOSZ, A., W. MAZIARZ, T. PISARKIEWICZ, H. BARSCH DE TORRES and J. MUELLER. A Micropreconcentrator Design Using Low Temperature Cofired Ceramics Technology for Acetone Detection Applications. *IEEE Sensors Journal*. 2013, vol. 13, iss. 5, pp. 1889–1896. ISSN 1530-437X. DOI: 10.1109/JSEN.2013.2245888.
- [24] GROVES, W. A., E. T. ZELLERS and G. C. FRYC. Analyzing organic vapors in exhaled breath using a surface acoustic wave sensor array with preconcentration: Selection and characterization of the preconcentrator adsorbent. *Analytica Chimica Acta*. 1998, vol. 371, iss. 2–3, pp. 131–143. ISSN 0003-2670. DOI: 10.1016/S0003-2670(98)00294-3.
- [25] LODEWYCKX, P., G. O. WOOD and S. K. RYU. The Wheeler-Jonas equation: a versatile tool for the prediction of carbon bed breakthrough times. *Carbon*. 2004, vol. 42, iss. 7, pp. 1351–1355. ISSN 0008-6223. DOI: 10.1016/j.carbon.2004.01.016.

- [26] SERRANO, G., S. M. REIDY and E. T. ZELLERS. Assessing the reliability of wall-coated microfabricated gas chromatographic separation columns. *Sensors and Actuators B: Chemical*. 2009, vol. 141, iss. 1, pp. 217–226. ISSN 0925-4005. DOI: 10.1016/j.snb.2009.05.003.
- [27] ALFEELI, B., L. T. TAYLOR and M. AGAH. Evaluation of Tenax TA thin films as adsorbent material for micro preconcentration applications. *Microchemical Journal*. 2010, vol. 95, iss. 2, pp. 259–267. ISSN 0026-265X. DOI: 10.1016/j.microc.2009.12.011.
- [28] RYDOSZ, A., W. MAZIARZ, T. PISARKIEWICZ, K. DOMANSKI and P. GRABIEC. A gas micropreconcentrator for low level acetone measurements. *Microelectronics Reliability*. 2012, vol. 52, iss. 11, pp. 2640–2646. ISSN 0026-2714. DOI: 10.1016/j.microrel.2012.05.012.

sensors, micropreconcentrators, microelectronics and exhaled breath analysis.

Dagmara MICHON (KWAPINSKA) was born in Krakow, Poland. She received his B.Sc. from AGH University in Science and Technology in 2013. She is currently pursuing the M.Sc. degree in electronic engineering. She research interests include gas sensors.

Krzysztof DOMANSKI was born in Warsaw, Poland. He received his M.Sc. and Ph.D. from Warsaw University of Technology, Poland, in 1996 and 2003, respectively. His research interests include MEMS technology.

Wojciech MAZIARZ was born in Nisko, Poland. He received his M.Sc. and Ph.D. from AGH University of Science and Technology in 1997 and 2006, respectively. His research interests include gas sensors, sensor arrays, and electronic nose applications.

Tadeusz PISARKIEWICZ was born in Opole, Poland. He received his M.Sc. from University of Opole in 1986, the Ph.D. from AGH University of Science and Technology in 1977, and currently he is a Full Professor in Department of Electronics AGH. His research interests include gas sensors, and measurement microsystems.

About Authors

Artur RYDOSZ was born in Ustrzyki Dolne, Poland. He received his M.Sc. and Ph.D. from AGH University of Science and Technology in 2009 and 2014, respectively. His research interests include gas